## Executive Summary

This research addresses a critical research need for California dairies: to better quantify air emissions from various sources and develop a process-based farm emission model. The objectives of this research were to (1) develop and refine sampling and analysis methodology and experimental protocols that allow for quantification of VOCs emitted from feed silage and dairy manure sources, (2) conduct experiments to quantify the generation and emission rates of VOCs from silage and manure under different management and environmental conditions and develop mathematical relationships between the generation and emission rates of VOCs and major controlling factors, and (3) to develop process-based computer models that can be used to predict the emission rates of VOCs from different silage and manure sources.

The results of this research allowed better understanding of the major VOCs generated and emitted from silage and manure sources on dairies with respect of their emission kinetics and quantities. The emission models developed are useful for estimating the emission rate and total emissions of alcohols and VFAs from silages and manure storages on dairies. The models can be further expanded in the future to include other VOCs by the application of similar research approaches, theories, and mathematical equations and computer algorithms. The major scientific findings and deliverables of this project are summarized as follows:

- Silage and manure emit many VOCs. On mass basis, ethanol, methanol, acetic acid, acetaldehyde and acetone were the major compounds emitted from both silages and manure sources. Ethanol is the predominant compound for silages and acetic acid is for manure. In-depth investigation and emission measurement and modeling were performed for these two compounds.

- The VOC emissions from silages are mainly controlled by mass transfer processes. A computer model was developed for predicting ethanol emission from silage exposed to an open air environment. Based on the input parameters of silage exposure surface area, silage density, ethanol concentration in the silage, air velocity and temperature, the models calculate the emission rate and total emission over time. Different types of silages have different emission kinetics due to the differences in ethanol concentration and other characteristics, such as density. Corn silage was found to have a higher ethanol emission rate than alfalfa silage. More research is needed to characterize different types of silages used on dairies so that silage characteristic data can be used to further develop and calibrate the ethanol emission models for their applications to a wide range of silages. Further studies are also needed to investigate the ethanol emissions during silage mixing and from deep silage layers or piles so that the ethanol emission models could be expanded to cover those operations.

- The VOC emissions from dairy manure are controlled by both microbial generation processes and mass transfer processes. Experimental data showed that ethanol generation in fresh manure increased with the temperature and time. A model was developed to estimate ethanol emissions from dairy free stalls and was validated using the data collected from an

environmental chamber. The input parameters for the model were number of cows, average weight of a cow, manure excretion rate, air flow rate and temperature, floor surface area, and kinetic constants of ethanol generation. The model outputs were ethanol emission rate and cumulative ethanol emission. The model needs to be calibrated and validated using more experimental data, under different experimental conditions, and farm measurement data.

- Manure solid content and storage temperature were found to be significant factors affecting microbial activities and their products. Higher total solid content and temperature correlated with more production of VFAs and alcohols in the manure. The research results indicate that alcohol emissions from dairy manure can be important during the first five days after excretion from animals and become negligible after the manure goes into storages. Emissions of VFAs, especially acetic acid, are predominant for manure storages. Computer models were developed to quantify the generation and emission rates of acetic acid from manure storages that receive manure of different solids content and exposed to different environmental conditions. The models can be expanded in the future to include other VOCs generated in the manure storages. Measurement data on dairy farms for the emissions of specific compounds are needed in order to fully calibrate and validate the emission models. The measurement data should include the characteristics and environmental conditions of emission sources as well as the emission rates and cumulative emissions over time.

- Because each of the emission sources on dairies has its own characteristics and emission profile, and different sources emit different types and amounts of VOCs, it is important to characterize and understand the physical, chemical and biochemical conditions in the sources that influence the VOC generation and emissions. Due to the large number of compounds emitted, individually modeling each of the dozens of VOCs emitted from dairy sources does not appear to be practical because of the magnitude of the tasks and limited resources. Emission modeling effort should be focused on the key compounds that have significant impact on the air quality, such as ozone formation, either by emission mass quantities or reactivities. The emissions of total VOCs may be estimated from the emissions of key compounds that can be modeled and the knowledge of their relative magnitude to the total VOC emissions, which could be determined through the measurements. Process-based emission models are mostly useful for estimating the emissions of key compounds under variable conditions, understanding the changes of emissions under different conditions, and determining the conditions that are responsible for most of the emissions.

- The advantages of process-based emission models are well recognized by scientific community and livestock industry as well as research sponsors, such as US Department of Agriculture, US Environmental Protection Agency, California Air Resources Board, and National Milk Producers Federation. It will take more significant resources and time to develop a processed based VOC emission modeling package that can be used to estimate the emissions, with reasonable accuracies, from individual sources as well as the whole farm but the undertaking and results of this project are significant accomplishments toward the overall goal.